

Deep Space Exploration: Will We Be Ready?

Infectious diseases, microgravity, and other forces affecting health pose challenges for humans planning to explore space

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"To prepare for the day when we are able to send scientists, engineers, and philosophers to study first hand the incredible discoveries our robotic field teams will surely unearth, we need to know more about biology--especially how space flight affects humans over long periods of time... We need to be able to handle medical emergencies in space flight. Returning to Earth for care will not be an option. And what about medical protocols in microgravity? In the 1/3 gravity of Mars? How about immune system response in variable gravity? How do we handle infections when we know that pharmacokinetics are altered in space flight? Clearly, we have a lot to learn."

--National Aeronautics and Space Administration (NASA) head Daniel S. Goldin, during the 98th General Meeting of the ASM, Atlanta, Ga., May 1998.

In contemplating space travel beyond earth orbits, we humans face significant barriers and major challenges. Although researchers involved in several scientific subdisciplines, including space medicine and space life sciences, may provide insights to help overcome those barriers, their efforts are at an early stage of development, leaving open many questions of potentially major consequence.

Nonetheless, studying the effects of living in microgravity for extended periods, such as those needed for travel to Mars, will be key to addressing these questions. From the space medicine perspective, the most important challenges center on devising means to prevent, diagnose, and treat diseases or conditions likely to affect those who participate in space missions to distant sites. In addition, the biological consequences of long-term exposure to space radiation need to be better understood because they carry serious implications for crewmembers involved in long duration missions.

As part of their overall efforts to promote a better understanding of these biological issues, NASA officials sponsored a conference, "The Pillars of Biology Initiative-Biomedicine Workshop, held in Houston, Texas, in September 1998. Experts outlined research priorities and practical measures that will be needed to protect the health of crew members on long-lasting space missions. Workshop participants considered specific concepts and strategies for an advanced, autonomous health-care capability to support humans on missions in deep space, such as the exploration of Mars.

Microbiological issues related to space exploration

Microorganisms play an integral role in human life on Earth. Our success in exploring space will depend on our ability not only to control the adverse effects of microorganisms but also to harness their remarkable metabolic capabilities. To move safely from short to long duration space missions, we will need to develop a better understanding of the microbial ecology of spacecraft, the effects of space flight upon human physiology and microbial functions, and on host-microbe interactions.

Plans now call for crew members aboard the International Space Station to spend long periods in space, as they prepare to establish lunar habitats and eventually to explore Mars. For these long-range plans to work, Space Station crew members will need to be protected from various sources of infectious disease, both on the ground and in the space environment.

Past experience demonstrates that reducing the exposure of crewmembers to potential pathogens before flights also reduces the incidence of infectious disease during those flights. Innovative research necessary to understand the host-microbe relationship in space include characterizing the effects of space flight on the human immune system and identifying the effects of space flight on complex microbial functions, particularly infectivity and pathogenicity.

Successful operation of long duration space missions also requires that the power of microbes be harnessed. Waste treatment and regenerative life-support systems required for long stays in space will depend on having available those specific species of bacteria and fungi that will be needed to transform complex organic materials such as human waste products into basic building blocks for reuse.

Microbiological Risks

Living and working for extended periods in the closed environment of spacecraft and using reconditioned air and recycled water pose difficult challenges to the scientists and engineers now contemplating such missions. Microbiological risks associated with space flight are expected to increase with the length in mission duration.

On Earth, microorganisms and humans maintain an intricate but precarious balance, one that will need to continue during long stays in space where conditions inevitably will vary from those that prevail at home. In space, microbes may adversely affect the health, safety, and performance of crewmembers by causing infectious diseases, inducing allergies, contaminating air, water, and surfaces, releasing volatile products, producing toxins, spoiling food, causing plant diseases, and degrading critical materials.

Thus many other manifestations of microbial contamination in addition to infectious diseases may jeopardize mission objectives. For example, allergic reactions to fungal spores, dust mites, and plant antigens may cause discomfort to sensitive crewmembers and thereby reduce their overall performance. While safeguards may exclude aggressive pathogens from space missions, changes in the immune response of certain crewmembers may render them susceptible to infections from otherwise harmless, commensal microflora.

The human-associated microbiota usually provide important protection from colonization by pathogens. However, endogenous infections may follow changes in the human-microbe relationship. Antimicrobial treatment and decreased immune responses are two of many factors responsible for shifts in the usual human-microbe balance.

Changes in human immune responses have been observed in both short and long-duration (>30 days) space flight missions. For instance, U.S. and Russian space scientists have identified several anomalies, including reductions in: 1) T-lymphocyte blastogenic response, 2) interferon-gamma production by mitogen-stimulated lymphocytes, 3) expression of interleukin-2 receptors, and 4) capacity of natural killer cells to lyse target cells. Also, cell-mediated delayed-type hypersensitivity to a panel of recall antigens was reduced among crew members during 3 - 5 day space missions.

Human-Microbe Interactions in space, actual and hypothetical

Microbial pathogens may prove to be especially problematic in spacecraft and space habitats because of the closed environment and relatively crowded living and working conditions that crew members will face. In case of certain infectious disease outbreaks, such as respiratory viral illnesses, it might be desirable to quarantine affected crewmembers to curtail spread, however the complex logistical considerations in designing quarantine procedures in enclosed spacecraft are simply not feasible. Moreover, quarantining would do little to reduce the threat of reactivation of latent viral infections such as those caused by herpesviruses.

When air and surface samples of Space Shuttle crew compartments from past missions were evaluated, about half of the surfaces sampled showed from 2- to 10-fold increases in bacterial counts following completion of those missions. Other samples indicate a similarly moderate increase in airborne bacterial levels by the end of missions. The bacterial species prevalent in such samples include those commonly associated with human habitation, such as *Staphylococcus* spp. Experiences aboard the Russian Mir Space Station provide another valuable means for studying microbial dynamics in a closed habitat--in this case, one that is inoculated periodically when new crew members are brought on board and the spacecraft is resupplied. As with the U.S. Space Shuttle, monthly air samples from the Mir indicate that the predominant bacterial species are of human origin. Moreover, according to these periodic air-sampling tests, *Aspergillus* spp. and *Penicillium* spp. are the most common fungal species found on Mir.

Generally, the microbial content of the Mir and U.S. Space Shuttle environments seems consistent with safe indoor air. However, moderate increases in airborne microorganisms, sometimes exceeding space flight standards, occurred following malfunctions of the Mir life support systems when humidity levels rose beyond normal limits. On such occasions, surface samples, collected from eight different locations in the Mir, yielded a variety of bacteria including *Staphylococcus* spp., *Micrococcus* spp., *Corynebacterium* spp., *Bacillus* spp., and *Enterobacter* spp. The most frequently isolated fungi were *Penicillium* spp., *Aspergillus* spp., and *Cladosporium* spp. However, when quaternary ammonium compounds and hydrogen peroxide were used to disinfect surfaces, microbial levels fell back within acceptable limits.

Conceivably, microbes could seriously contaminate the air and water supplies aboard a space station, compromising its habitability and interfering with mission objectives if crewmembers

become ill or experience significant discomfort. If life support systems become severely contaminated--for instance, if bacterial biofilms form within the water reclamation treatment apparatus-- system failure could force the crew to scuttle a mission. Production of volatile organic compounds from other reclamation systems might release objectionable odors or toxins into the enclosed environment. Additionally, the release of non-volatile microbial products, such as aflatoxins, may cause acute toxicity or delayed effects, such as carcinogenesis, among crew members.

Crewmembers face other hazards from microbes, which may cause food spoilage or degrade critical materials needed within the station or, in the case of extra-vehicular activity (EVA) suit materials, for excursions outside it. Crewmembers facing long-duration missions will likely carry--and try to cultivate-- green plants as sources of food and for air and water purification in the advanced life support systems. Plant pathogens, not usually a human disease concern, have the potential to destroy these plants that will be critical for long-term success of certain missions.

Planning for biological needs on long-term space missions

Ambitious missions involving lengthy stays on the moon and Mars will introduce increased microbiological risks to crew health and to the integrity of their space habitats. Whatever the mission, microorganisms will accompany the crews and will become firmly established in the spacecraft or space habitat. Far more remains to be learned about human-microbe relationships under the circumstances of space flight to minimize the risk to the crews and to the integrity of their space habitats.

Although NASA has no immediate plans for human flight programs beyond low Earth orbit, officials at the agency are responsible for defining and developing the basic research and technical developments that would make such exploration-class missions feasible. Thus, the agency has been reaching out to a wide range of organizations that may contribute to the effort.

For example, in September 1998, NASA officials convened the Pillars of Biology Initiative-Biomedicine Workshop, held in Houston, Texas. Participants included representatives of 18 professional scientific and engineering societies, three government agencies, two NASA advisory committees, and a national health policy institute. Participants considered specific concepts and strategies for an advanced, autonomous health-care capability to support humans on missions in deep space, such as the exploration of Mars.

Workshop participants focused on two principal programmatic elements of the NASA life sciences program: development of countermeasures to the deconditioning effects of microgravity and space medicine. Specifically, scientists active in the NASA Biomedical Research and Countermeasures (BR&C) Program are being asked to develop a better understanding of the effects of space flight on humans and the underlying mechanisms of these effects. Applied research activities within this program aim to develop countermeasures for preventing undesirable health effects of space flight on humans.

Meanwhile, the NASA Space Medicine Program focuses on the development of policies and requirements for clinical care and medical research to support extended space flights. The goal is to

develop systems and technology that ensure the health of crewmembers and minimize the impact of adverse medical events on mission success. The space medicine program consists of several projects to ensure the health, safety, and performance of flight crewmembers on space missions.

NASA has invested substantially in space life sciences research over the past 30 years. For instance, that research has helped to reveal the significant physiological and psychological effects of long-term exposure to microgravity. However, little is yet known about effective countermeasures to those deconditioning effects--an important priority of the NASA space medicine and countermeasures development initiative in the 21st century.

The effects of microgravity are not the only health concerns raised by long-term space missions. Experiences of crewmembers during a series of 3-4 month Mir missions also raise concern regarding medical, physiological, and psychological effects of such missions. Moreover, medical incidents in isolated environments such as at the Antarctic research station suggest that there could be at least one major medical event on a three-year mission to Mars with a crew of six or more. If crews on such missions were to be equipped with the standard medical equipment and supplies that NASA missions now carry, they would face extraordinary challenges in coping with many, if not most major medical crises.

Modifying ordinary approaches to clinical care for application in space will not be a simple process. For one thing, crewmembers practicing medicine in space will need to address the classical triad of prevention, diagnosis, and treatment while coping with microgravity and, necessarily, limited supplies and equipment. For another, they will require equipment that can function in the space environment. Appropriate skills must be identified for those who will deliver health care in space, and they must be trained in the field of space medicine.

Recommendations for NASA Biology and Medicine Programs

Participants at the NASA Pillars workshop urged agency officials to expand space medicine programs in general and to develop specific deconditioning countermeasures needed to support an exploratory space mission. One such specific countermeasure for NASA to consider developing is "artificial gravity," including studies of how intermittent acceleration forces plus exercise versus the continuous application of acceleration forces at varying levels might affect the physiologic responses of crew members.

Before NASA is ready to launch an exploration class space mission, officials will need to scrutinize advances in medicine from on-going research and development efforts throughout the public and private sectors in the United States and elsewhere for technologies that could be adapted to use in space.

Meanwhile, NASA needs to expand its own space medicine and medical operations research and development efforts. Only recently have experts begun to recognize some of the specific medical risks associated with space exploration. For example, experiences of crewmembers who have participated in the U.S.-Russian Shuttle/Mir Program point to a number of previously unappreciated medical risks, including wound healing, the pharmacological and pharmacokinetic implications of specific medical therapies such as antibiotics, and the challenges associated with

conducting surgical procedures in space. Workshop participants urged NASA officials to develop a strong intramural space medicine research program and, if possible, to expand the agency's investments in this area.

Despite a considerable investment in biomedical research and disease countermeasures over the past several decades, current spending in these areas falls below levels deemed necessary to support human exploration space missions within the next 10 years. However, with changes in priorities and augmented spending, NASA is well positioned to address those important challenges, according to workshop participants.

NASA officials thus face a dilemma. Near-term commitments to launch and assemble the International Space Station necessarily curtail spending of resources for long-lead-time exploratory missions. However, postponing critical research in space medicine and disease countermeasures may mean that critical technologies to protect crew members will not be in hand when those missions are otherwise ready to launch. Conceivably, NASA will be forced to undertake some of that space medicine research to meet an unnatural, hurry-up schedule. Indeed, if certain life sciences research projects do not prove successful under such circumstances, we may someday be facing difficult choices-- between delaying launches or accepting higher risks for the crewmembers slated to travel on those missions.

Suggested Reading

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Reference Mission Exercise: Humans Explore Mars

NASA officials have developed a scenario, consisting of a hypothetical mission to Mars, to help focus attention on practical challenges entailed in long-term space missions. During the Pillars of Biology Initiative-Biomedicine Workshop, held in Houston, Texas, participants used this scenario as a tool to evaluate systems that will be needed to protect the health of crewmembers undertaking such missions.

This scenario provides participants with several specific assumptions on which to base their evaluations. For instance, the 6-membered crew can expect to travel to Mars relatively rapidly, within 4 to 6 months; they will be exposed to a microgravity environment during transit; will stay on the surface of Mars for approximately 600 days; were chosen to minimize health and behavioral issues; can count on communications delays with mission control while on Mars; face a strong possibility of failure of microgravity countermeasures due to deconditioning during transit as well as the possibility of illness or medical emergency beyond diagnostic and treatment capability of crew; face other environmental hazards and risks; and require protection against radiation as well as equipment to supply air, food, water, and other basic needs while working on the Mars surface.

On top of these requirements, NASA officials and workshop participants identified other practical challenges in choosing a crew for such a mission, including: current approaches to selecting crews, including applicable behavioral and health criteria, may be inadequate for a mission to Mars; and current standards for medical care, nutrition, radiation protection, and disease and hazard countermeasures also seem inadequate for such a mission.

With those needs in mind, workshop participants identified and ranked critical issues for planning a mission of humans to Mars. They also identified strategies that NASA might use--as well as the human and financial resources that would be required -- to resolve these critical issues.